OBSERVATIONS OF LOW-AMPLITUDE BRIGHTNESS OSCILLATIONS IN THE UNUSUAL ECLIPSING SYSTEM V718 PER (HMW 15, H 187)

O. Barsunova[1], V. Grinin[1,2], A. Arkharov[1], S. Sergeev[3], S. Shugarov[4]

[1] Central Astronomical Observatory (Pulkovo), St. Petersburg, Russia, *monoceros@mail.ru*
[2] Sobolev Astronomical Institute, St. Petersburg State University, St. Petersburg, Russia
[3] Crimean Astrophysical Observatory, Nauchny, Crimea, Ukraine
[4] Sternberg Astronomical Institute, Moscow State University, Moscow, Russia

ABSTRACT. The unusual young star V718 Per is known its prolonged eclipses with a period of 4.7 years. In additional we have discovered that for the last observational seasons (2008–2010) the low-amplitude oscillations are presented at the star's light curve and their period is approximately a factor of 8 shorter that the main one. In contrast to the large-scale eclipses accompanied by the star's reddening, the low-amplitude oscillations are neutral in character. So bimodal behavior can be the result of the division a circumstellar disk into two parts: an inner, dense region, and an outer, less dense disk, with a large cavity between them. Such structures emerge in the presence of a fairly massive perturbing body (or bodies) in the disk. In this case, density waves rotating with different angular velocities can be formed in each of these parts. Therefore, when such a system is observed nearly edge-on, two oscillation modes with different periods can be present in the extinction variations. We suggest that such a situation takes place in the case of V718 Per. In that case the perturbing body (or bodies) can be either a giant planets or a brown dwarfs, because of this star exhibits no signatures of spectroscopic binarity.

Key words: young eclipsing systems, photometry, protoplanetary disks; stars: individual: V718 Per.

1. Introduction

The star V718 Per belongs to the subclass of young weak-line T Tauri stars characterized by a low level of accretion activity and weak infrared excesses, indicative of a small amount of circumstellar dust. It is, therefore, very surprising the fact that this star exhibits photometric activity caused by large-scale circumstellar extinction variations. The pattern of this activity, a sequence of extensive eclipses whose duration (3.5 yr) is comparable to the period between them (4.7 yr), is also unusual.

The results of our (Barsunova et al. (2005), Grinin et al. (2006, 2008)) and other authors (Cohen et al. (2003), Nordhagen et al. (2006)) photometric observations are shown that the eclipses parameters and shape rather close. Hence, it followed that the stars eclipses are produced by the passages of the same extended dust (or gas-dust) structure through the line of sight. A Fourier analysis of this light curve obtained yields a period of P = 4.7 yrs.

During the eclipse, the star reddened according to a law that did not differ greatly from the standard interstellar reddening law (Grinin et al. (2008)). Note that the shape of the color-magnitude diagram indicate on changing of the characteristic size of the dust particles in the extended structure .

The arrows in the light curve (Fig.1) show dates with the spectroscopic observations. Analysis of two high-resolution spectra taken by G. Herbig with the Keck telescope showed that the spectrum of V718 Per had no spectroscopic signatures of the secondary component. So, V718 Per is most likely a single star and that only a low-mass companion (a brown dwarf) or a proto-planet could be a source of perturbations in the circumstellar disk causing periodic extinction variations.

It was found from the spectral energy distribution for V718 Per (Grinin et al.(2008)) that the circumstellar disk has an inner matter-free gap with a radius of the order of several astronomical units. At the same time, the high extinction toward the star, much of which is produced by circumstellar extinction, indicates that the disk is seen nearly edge-on.

In this paper we present last results of our optical and near-infrared photometry for V718 Per obtained during the 2008-2010 observing seasons.

2. Observations

The optical observations of V718 Per were carried out at the 0.7-m AZT-8 telescope of the Crimean Astrophysical Observatory. The observations were reduced to the Johnson-Cousins photometric system. We measured the stars brightness by the method of aperture photometry. The resulting accuracy of the aperture photometry for V718 Per is determined by the errors of the method and the brightness fluctuations of the comparison stars; it is $0^m.03$ in the V and R bands and about $0^m.02$ in the I band. The photometric technique and information about the comparison stars are presented in more detail in Grinin et al. (2008).

Our infrared photometry in the J,H,K bands was performed with the Pulkovo 1.1-m telescope at the Campo Imperatore Observatory (Italy). We reduced the observations to the standard Johnson system. The accuracy of the photometry is about $0^m.02$ in all three bands.

3. Results

3.1. The Optical Light Curve

Figure 1 shows the I-band light curve of V718 Per from our observations supplemented by the observations of the previous eclipse from Cohen et al. (2003) and by the data of Nordhagen et al. (2006). One can see from this figure that, in addition to the large scale brightness variations with a period of 4.7 yr, the star exhibits also the low-amplitude oscillations with a shorter characteristic time. They are also clearly seen in the V- and R-band light curves.

Such oscillations were not detected earlier due to large gaps in the previous observations.

3.2. O–C Analisys

Using the standard procedure of O-C analysis, we attempted to isolate the low-amplitude oscillations from the stars light curve. Figure 2 shows the results of our Lomb-Scargle periodogram analysis of the O-C residual. We see that a strong peak exists in the power spectrum. The corresponding period is 213 days, or approximately 1/8 of the period between the eclipses.

Figure 3 shows the O-C residual folded with this period. The thin line indicates the model (a sine wave with the 213–day period) providing the best fit to the

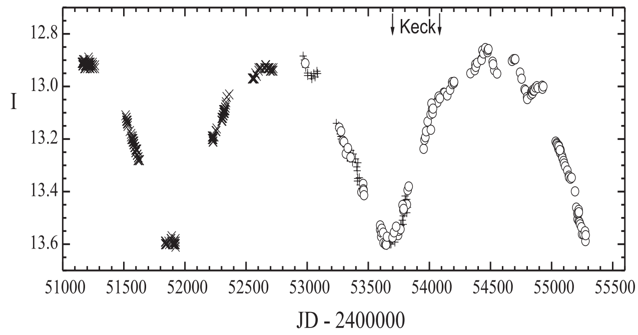

Figure 1: I-band light curve of V718 Per from our observations (○) and the data of Cohen et al. (2003) (×) and Nordhagen et al. (2006)(+). The arrows indicate the times of the spectroscopic observations.

observations. We see that the scatter of points in the O-C residual about the model is rather large due to both the small amplitude of the oscillations and the insufficient accuracy of the smoothed light curve based only on two eclipses.

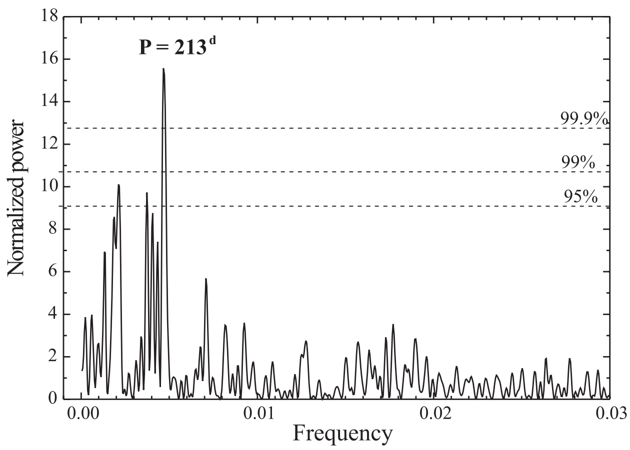

Figure 2: Lomb-Scargle periodogram for the O–C residual of the light curve for V718 Per.

3.3. The Neutral Character of the Low-amplitude Brightness Oscillations

Analysis of the low-amplitude oscillations showed that they have the neutral character. It is clearly seen from Figure 4 with the fragment of the out-of-eclipse light curve in the VRI bands. The same conclusion follows also from the analysis of the IR bands.

The IR observations are more fragmentary than the optical photometry due to the schedule of the infrared observations. Nevertheless, the low-amplitude oscillations are also can be seen in all three JHK light curves (Fig. 5). They occur synchronously with the optical brightness oscillations and, what is particularly inter-

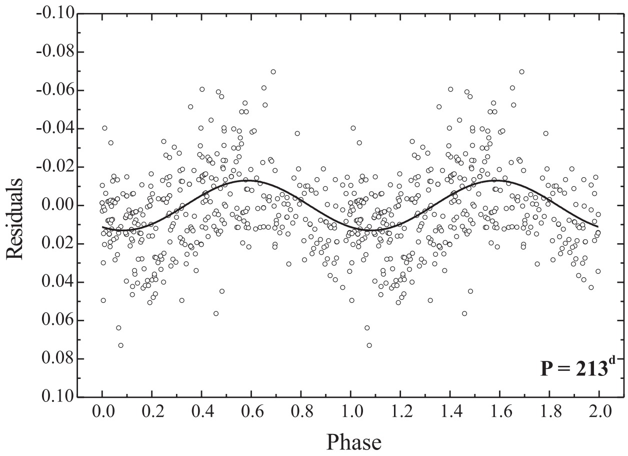

Figure 3: Phase light curve of the O–C residual folded with a 213–day period. The thin line indicates the model (a sine wave with the 213–day period).

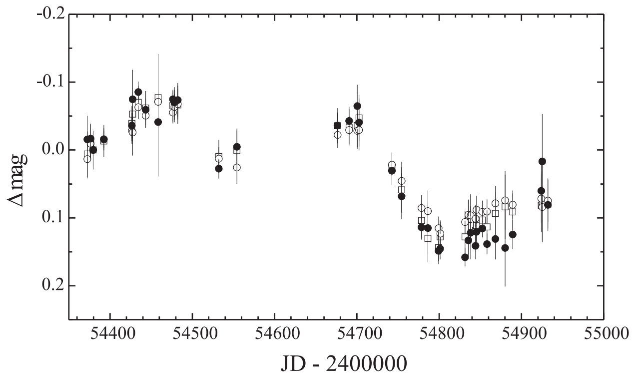

Figure 4: Diagram illustrating the neutral character of the low-amplitude brightness oscillations in V718 Per in the V, R, I bands. Fragments of the stars normalized V (•), R (□), and I (○) light curves in the interval JD = 2 454 372–2 454 789 are shown. The magnitudes in all three bands are taken to be zero at JD = 2 454 382.5.

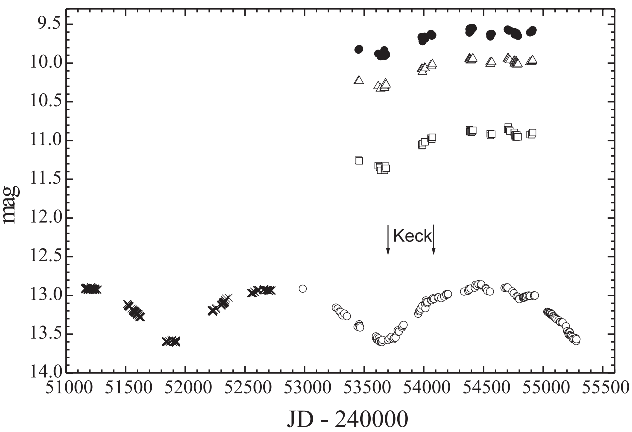

Figure 5: J (□), H (△), and K (•) light curves of V718 Per. The I-band light curve of the star from the data of Cohen et al. (2003) (×) and our observations (○) is shown below for comparison.

esting, the amplitude of these oscillations, does not depend (or depends very weakly) on the wavelength.

This is clearly seen from Figure 6 which shows the same fragment of the light curve. The magnitudes in these bands are normalized in the same way as for the VRI bands.

So, the low-amplitude oscillations differ greatly from the large-scale eclipses whose amplitude increases toward the short-wavelengths (as can be clearly seen from Fig. 5).

4. Discussion

The SPH simulations (Sotnikova and Grinin (2007), Grinin et al. (2010)) show that the bimodal brightness oscillations caused by variations of circumstellar extinction can appear in young binary systems. Interestingly, the ratio of the periods of two brightness oscillation modes in such models is about 5-7, i.e., it is close to what is observed in our case. Nevertheless, despite this coincidence, the model is unsuitable, because the assumption about the binarity of V718 Per is in conflict with the results of its radial-velocity measurements, indicating that the star is a single one.

The neutral character of the low-amplitude brightness oscillations means that the periodic extinction variations causing these oscillations are attributable mainly to large particles with characteristic sizes greater than one micrometer. At the same time, small dust grains with sizes of the order of several tenths of a micrometer make a major contribution to the extinction in large-scale eclipses whose amplitude grows with decreasing wavelength. This fact suggests that the bimodal brightness oscillations in V718 Per can be due to a two-component structure of the circumstellar disk, which consists of inner and outer disks separated by a matter-free (or almost matter-free) gap (see Fig. 7). The grain coagulation processes have a higher rate in the inner disk because of the higher matter density. Therefore, the contribution of large particles to the extinction here will be greater than that in the outer disk.

A two-component structure of the circumstellar disk like that shown in Figure 7 is well known from the theory of protoplanetary disks perturbed by a giant planet or a substellar companion (see, e.g., de Val–Borro et al. (2007)).

The calculations by these authors show that cyclonic structures can arise in a protoplanetary disk perturbed by a giant planet. In the course of evolution, they form two giant cyclones that move with local Keplerian velocities on opposite sides of the inner gap in the disk. If such disk is inclined at a small angle to the line

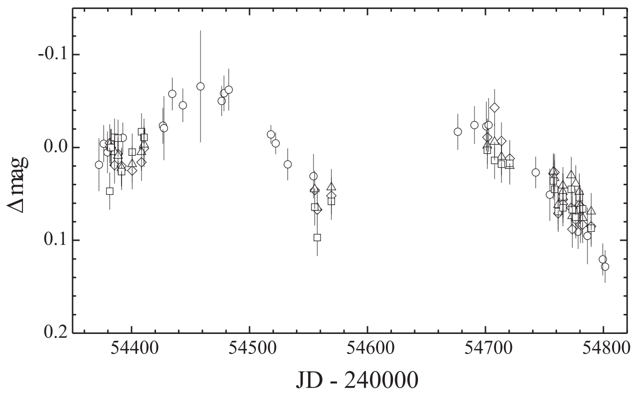

Figure 6: Diagram illustrating the neutral character of the low-amplitude brightness oscillations in V718 Per in the I, J, H, K bands. Fragments of the stars normalized I (○), J (◇), H (△), and K (□) light curves in the time interval JD = 2 454 372-2 454 789 are shown. The magnitudes in all four bands are taken to be zero at JD = 2 454 382.5.

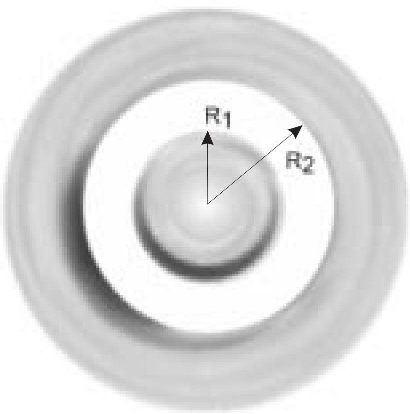

Figure 7: Scheme of the two-component circumstellar disk model for V718 Per.

of sight, then extinction variations with two different periods can be observed due to the rotation of the two giant cyclones.

Thus, the bimodal pattern of extinction variations observed in V718 Per is, in principle, compatible with the present-day models of circumstellar disks perturbed by low-mass companions or protoplanets.

The observationally very unusual photometric variability of V718 Per described above actually has a certain similarity with the activity cycles of UX Ori stars. This similarity means that, in both cases, the cyclic brightness variations are due to recurrent passages of giant gasdust structures through the line of sight. We associated such structures with periodic perturbations in the circumstellar disks generated by low-mass companions or protoplanets.

So, V718 Per has analogues among young stars. However, it should be noted that the cyclic activity of UX Ori stars is observed against the background of strong stochastic variability, making its study difficult. In contrast, in the case of V718 Per, we are dealing with an object that is considerably more convenient for studying fine features of the light curve.

Acknowledgements. We are grateful to N.Ya. Sotnikova, D.V. Bisikalo, N.N. Chugai, and A.A. Kilpio for helpful discussions. We also thank S.V. Klimanov for help with the observations and K.N. Grankin for consultations on the statistical methods for reducing observations. This work was performed in the context of the Origin and Evolution of Stars and Galaxies Program of the Presidium of the Russian Academy of Sciences and was supported by grants NSh-6110.2008.2 and NSh-1318.2008.2.

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